MAGIC hyperspectral observations for studying cloud properties

A. Marshak (NASA GSFC),
P. McBride (GESTAR/ASTRA), C. Chiu (University of Reading)
W. Wiscombe (NASA GSFC)

What am I doing? What can I offer/share? What do I need?

'Permanent' hyperspectral instruments

Instrument	Location	Status	Dates	Notes
SWS (Shortwave Spectroradiometer)	SGP	Calibrated	11.2013-Present 	Note in the archive mentions InGaAs temperature too high from 4.2011 to 10.2013 ***From Connor:*** Note in the archive regarding InGaAs temperature is erroneous. That problem is long since fixed. I'm working on reviewing the DQR to provide an appropriate end-date.
SAS-He (Shortwave Array Spectroradiometer – Hemispheric)	SGP	Calibrated	4.2012-Present 	***From Connor:*** Calibrated irradiances and AOD available on the DMF under /data/home/ermold/data/datastream/sgp/
SAS-Ze (Shortwave Array Spectroradiometer – Zenith)	SGP	Uncalibrated	3.2011-7.2012 	***From Connor:*** The SAS-Ze was moved to the AMF2 for Magic in 7.2012 and will be returned to SGP in Nov 2013 with new calibration. Calibrated data from SGP should flow immediately as we now have the ingest released. I will then work on determining the calibration for the previous period 3.2011-7.2012.
RSS (Rotating Shadowband Spectroradiometer)	SGP	Some data in archive	6.2003-9.2007 	Most recent data is waiting to be processed after some personnel turn over

Field deployed hyperspectral instruments

Instrument	Location	Status	Dates	Notes
HydroRad	RACORO (SGP)	Uncalibrated and not in archive.	1.2009-6.2009	Andy Vogelmann is close to providing this aircraft-based calibrated data.
SAS-HE	GVAX (India)	Data in archive	2.2012-4.2012	***From Connor:*** Very limited data set due to mechanical failure combined with monsoon. Langley calibration and AOD may be possible for this limited 2 month period.
SAS-Ze	GVAX (India)	Uncalibrated	2.2012-4.2012	***From Connor:*** Dubious calibration.
SAS-HE	TCAP (Cape Cod)	Calibrated	7.2012-6.2013	***From Connor:*** Mobile facility, not yet in archive but calibrated irradiances and AOD available on research.dmf.arm.gov under /data/home/ermold/data/datastream/pvc
Aerodyne	TCAP (Cape Cod)	Available?		Aerodyne had a "guest" spectrometer with wavelength range between 350-1000 nm (roughly). I have not spoken to them about their willingness to share data.
SAS-Ze	TCAP (Cape Cod)	Calibrated	6.2012-72013	***From Connor:*** Not sent to archive yet but calibrated data available on research.dmf.arm.govunder /data/home/ermold/data/datastream/pvc
SAS-Ze	**MAGIC (Pacific)**	**Calibrated**	**10.2012-9.2013**	***From Connor:*** **Not sent to archive yet but calibrated data available on research.dmf.arm.gov at /data/home/ermold/data/datastream/mag**
SSFR	**MAGIC (Pacific)**	**Not in archive**	**7.2013-9.2013**	**Not in the archive yet, but I have calibrated data**

Multichannel instruments (overlapping with hyperspectral only)

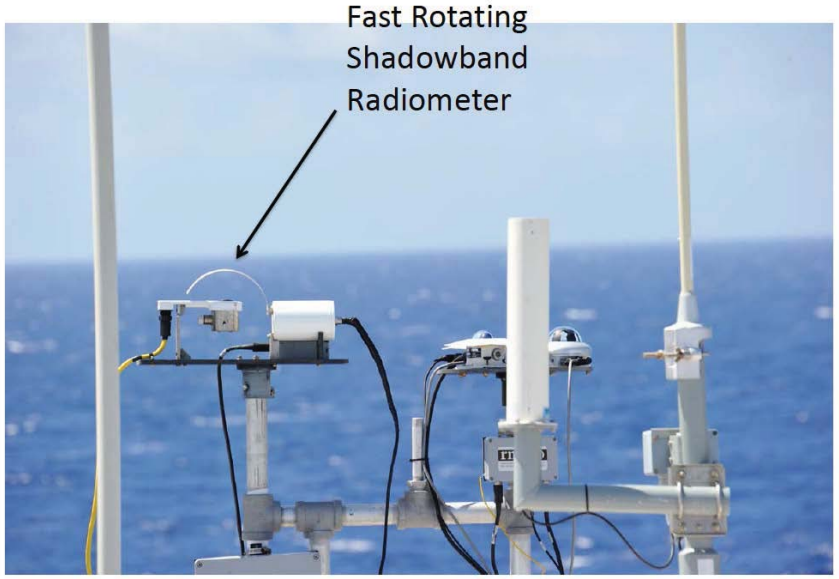
Instrument	Location	Status	Dates	Notes
Cimel	SGP	In archive	4.1994-10.2013	
MFRSR	SGP	In archive	2.1997-10.2013	
NFOV	SGP	In archive	9.2004-6.2007	Gaps in this range, but data is “generally available” in the archive.
Cimel	GVAX (India)	In archive	8.2011-4.2012	Cimel data in archive are very sparse between 8.8.2011 and 9.28.2011 (according to a data note in the archive).
MFRSR	GVAX (India)	In archive	6.2011-3.2012	
Cimel	TCAP (Cape Cod)	In archive	7.2012-7.2013	
MFRSR	TCAP (Cape Cod)	In archive	7.2012-5.2013	
2-NFOV	TCAP (Cape Cod)	In archive	7.2012-7.2013	
Cimel	**MAGIC (Pacific)**	**Not in archive**		
Fast Rotating Shadowband MFR	**MAGIC (Pacific)**	**Not in archive**		

Solar Spectral Flux Radiometer (SSFR)

Radiation Instruments @ MAGIC

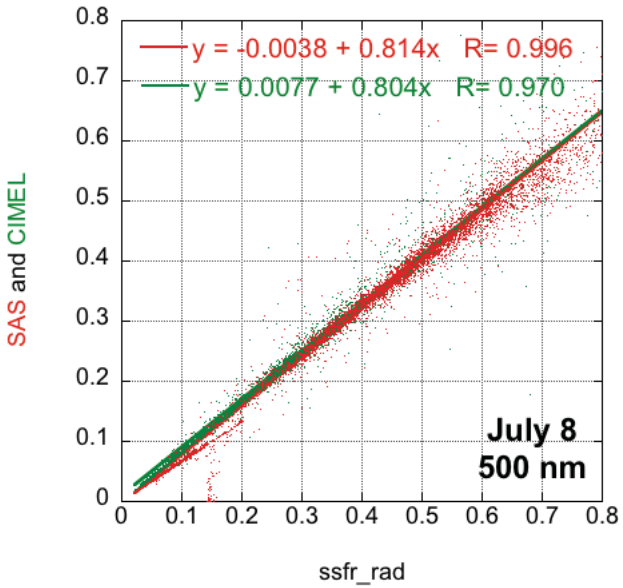
Solar Array
Spectrophotometer

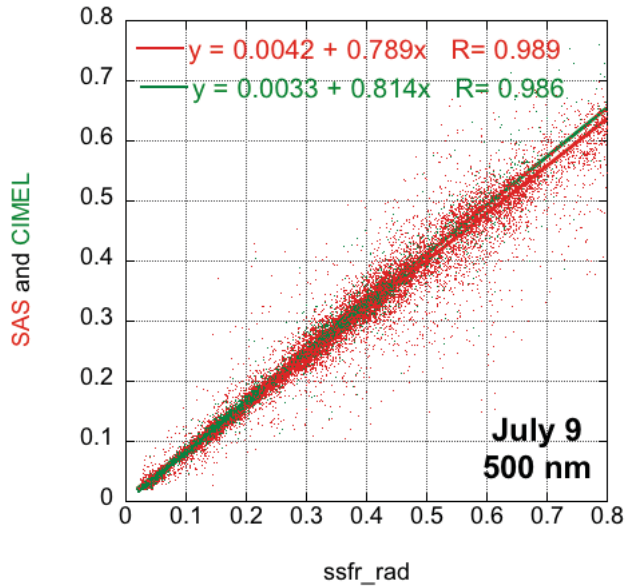
CIMEL Sunphotometer
operated in cloud mode



From Ernie's MAGIC slide show

Consistency between different instruments

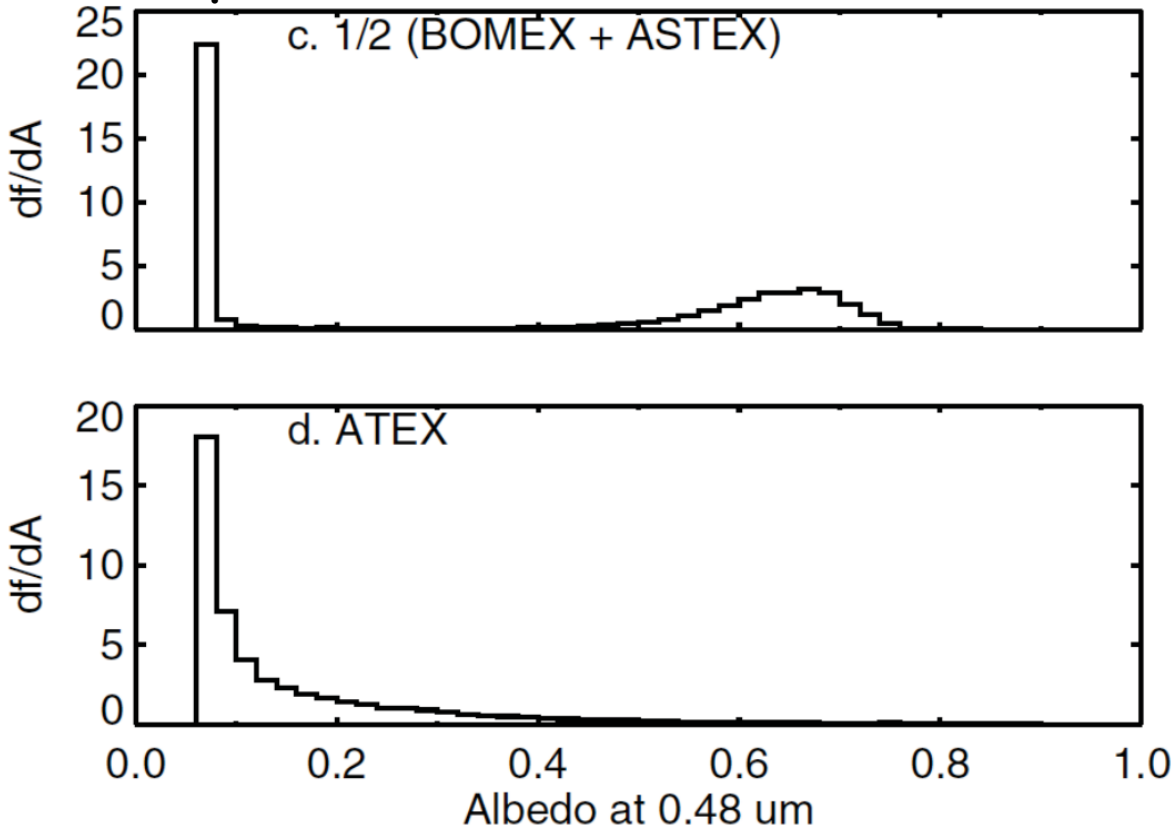




This is 500 nm; there are some issues yet for 1600 nm

Inseparability of cloudy and clear skies under partial cloud cover (from Charlson et al., 2007)

Albedo pdfs from LES of trade Cu and Sc clouds



average of the BOMEX (~10% cloud cover) and ASTEX (overcast) fields; clear and cloudy contributions are nicely separated

for ATEX trade Cu (~50% cloud cover), with the albedos from clear and cloudy portions inseparable

"The existence of partly cloudy regions and the fact that the clear-cloudy distinction is ambiguous and aerosol dependent raise the possibility that the conventional expression may lead to errors." (Charlson et al., 2007)

Twohy et al. (2009)

estimated that "*the aerosol direct radiative effect as derived from satellite observations of cloud-free oceans to be 35–65% larger than that inferred for large (>20 km) cloud-free ocean regions.*"

Chand et al. (2012)

found a 25% enhancement in AOT between CF 0.1-0.2 and CF 0.8-0.9. This *"enhancement is consistent with aerosol hygroscopic growth in the humid environment surrounding clouds."*

Our goal is ***interpret spectral radiative measurements in terms of aerosol and cloud properties in the transition zone in fully 3D cloud situations***.

What do we expect to achieve? Using *the spectral methods* applied to MAGIC shortwave spectrometer measurements, we will be able to:

- *understand sources of particle changes* ranging from aerosols swelling in humid air, and the detrainment of cloud-processed particles into the cloud-free environment, to the presence of undetected clouds;
- *distinguish between aerosol particles and weak cloud elements;*

- *test the hypothesis of cloud inhomogeneous mixing* in a new way.

As a result,
we expect to improve the estimates of aerosol radiative forcing and aerosol indirect effects as a function of cloud and aerosol microphysical properties

Spectral-invariant hypothesis

$$I_{transition}(\lambda) = aI_{cloudy}(\lambda) + (1-a)I_{clear}(\lambda),$$
$$a \in (0,1),\ a \neq a(\lambda)$$

$$\frac{I_{transition}(\lambda)}{I_{clear}(\lambda)} = a\frac{I_{cloudy}(\lambda)}{I_{clear}(\lambda)} + (1-a)$$

$$(i)\ \ y(\lambda) = ax(\lambda) + b$$

$$(ii)\ \ b \equiv 1-a$$

Radiative transfer calculations

Use SBDART (1D) to calculate zenith radiance

- 400-2200 nm with 10 nm resolution

Atmosphere

- mid-latitude summer
- 3 cm water vapor column

Aerosol

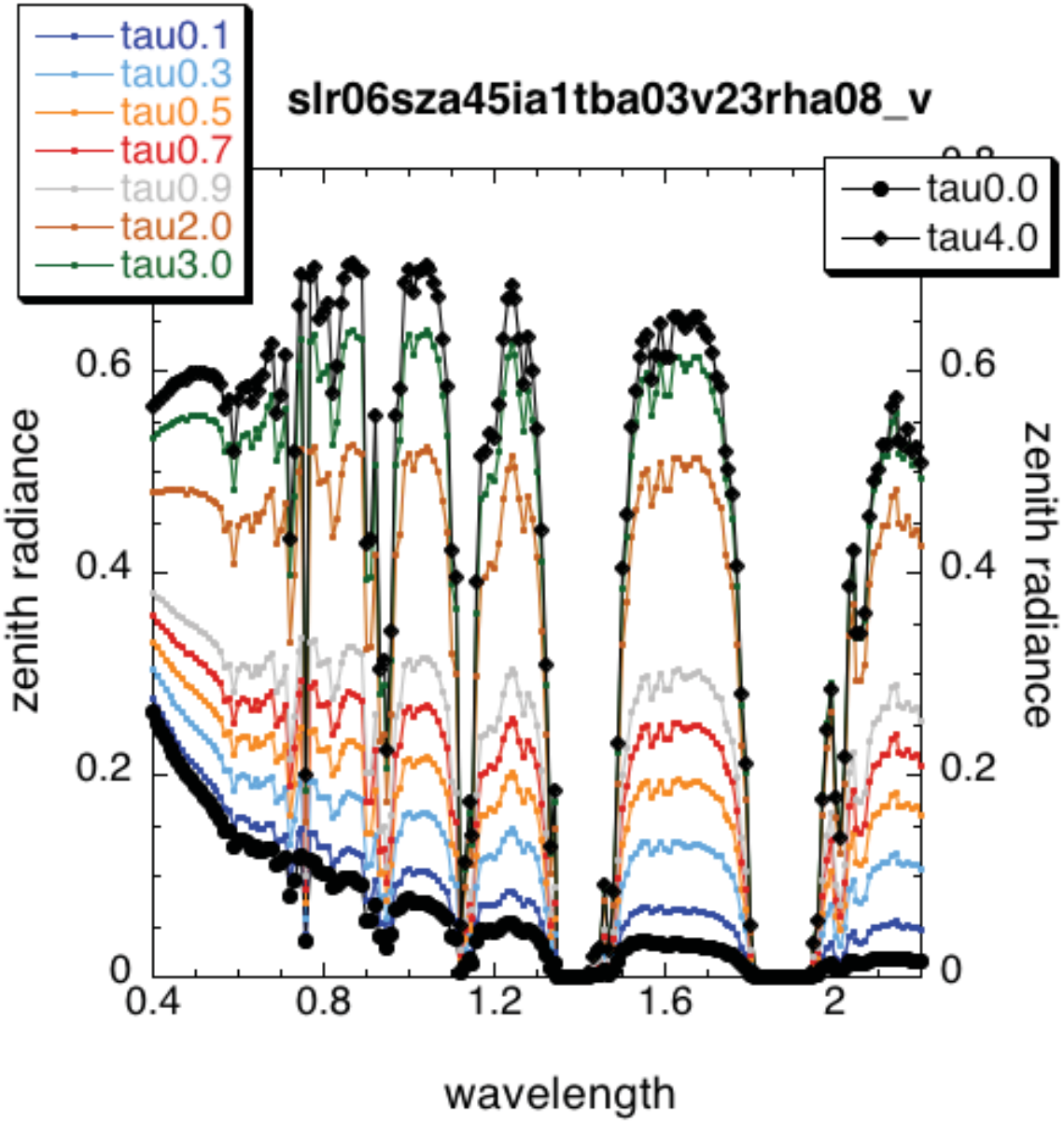
- 0.2 – 1 optical depth at 550 nm (rural)
- 80% relative humidity

Cloud

- 0-4 cloud optical depth (at 550 nm)
- 1 km altitude

from Chiu et al.,ACP 2010

SBDART model spectra: cloud opt depth from 0 to 4



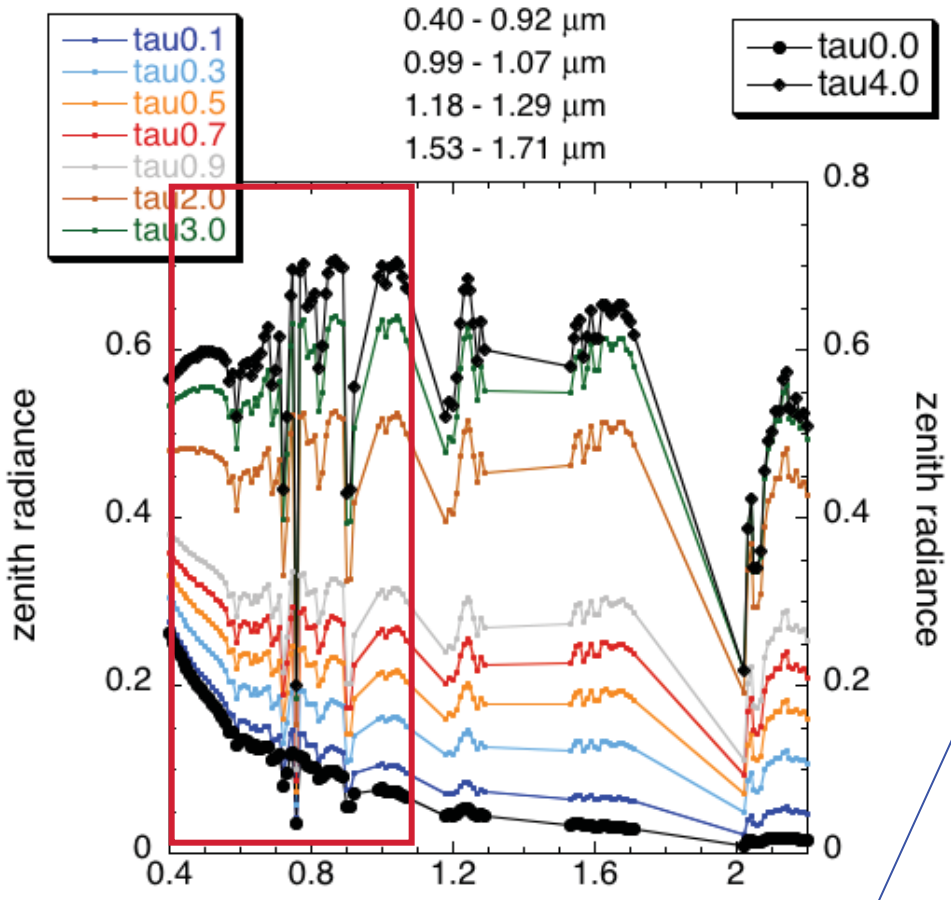
SZA = 45°

r_{eff} = 6 µm

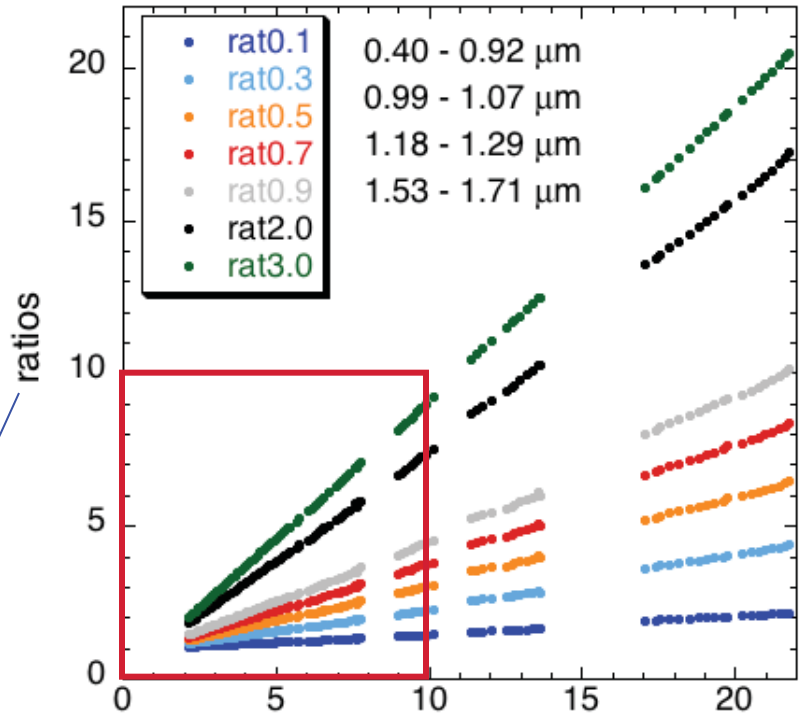
AOD = 0.3

Vegetated surface

SBDART model: spectra omitting absorption bands (l), spectral-invariant plot (r)

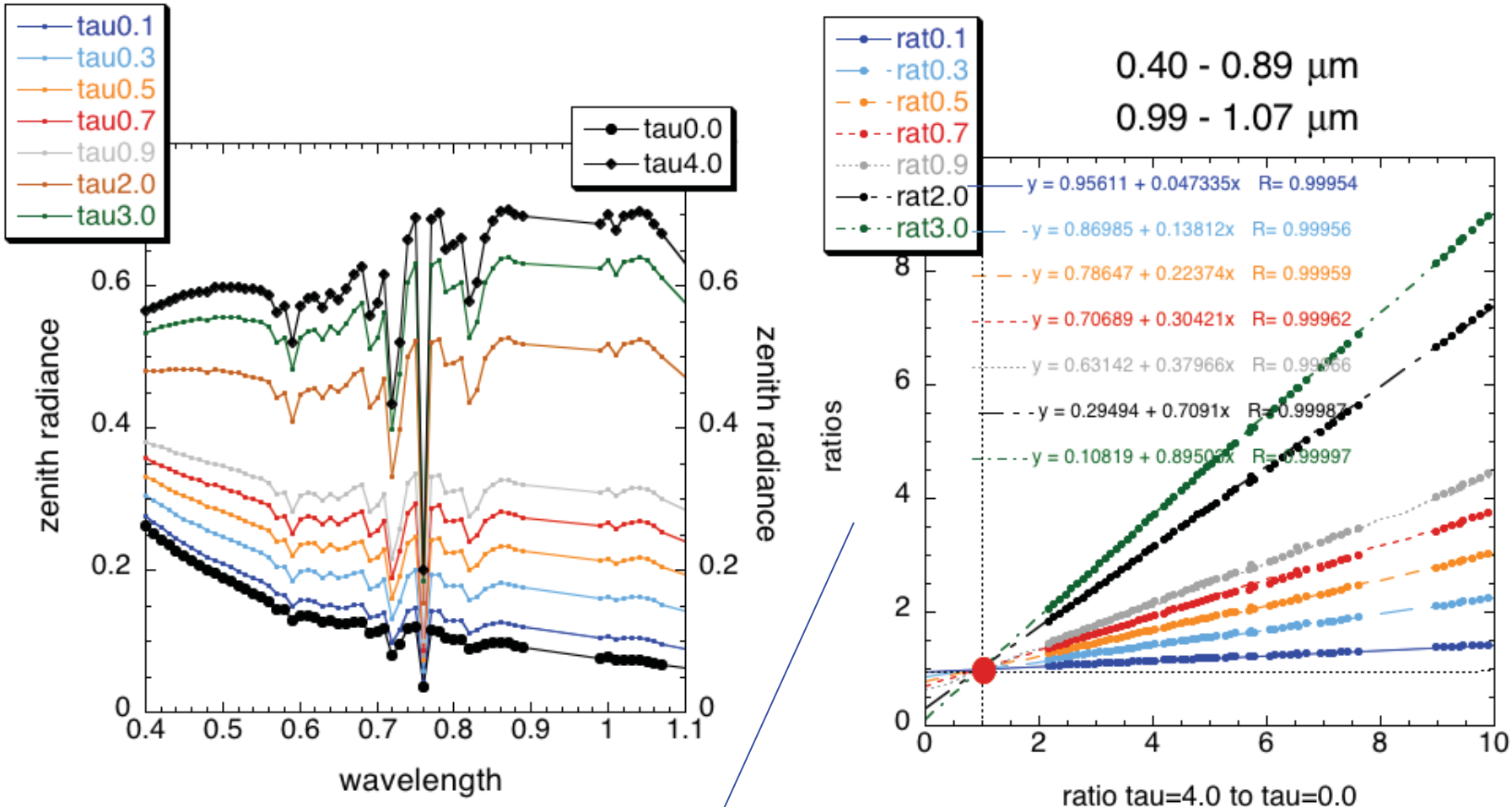


zooming in on red-box regions in next slide



$$\frac{I_{transition}(\lambda)}{I_{clear}(\lambda)} = a\frac{I_{cloudy}(\lambda)}{I_{clear}(\lambda)} + (1-a)$$

SBDART model: short spectra omitting 0.9-1 μm (l), spectral-invariant plot (r)



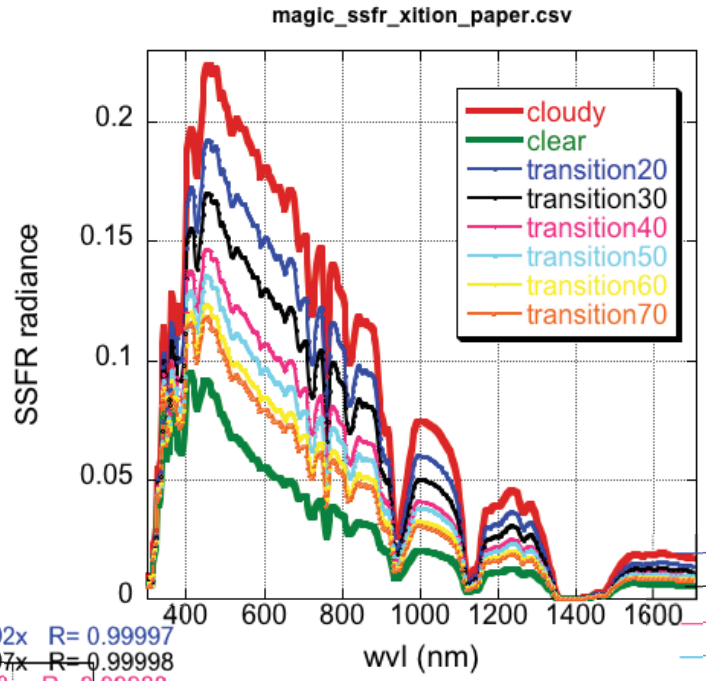
$$\frac{I_{transition}(\lambda)}{I_{clear}(\lambda)} = a\frac{I_{cloudy}(\lambda)}{I_{clear}(\lambda)} + (1-a)$$

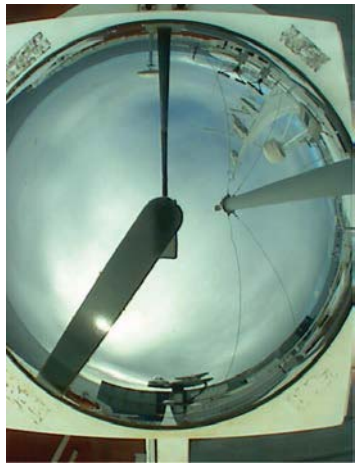
Publication:

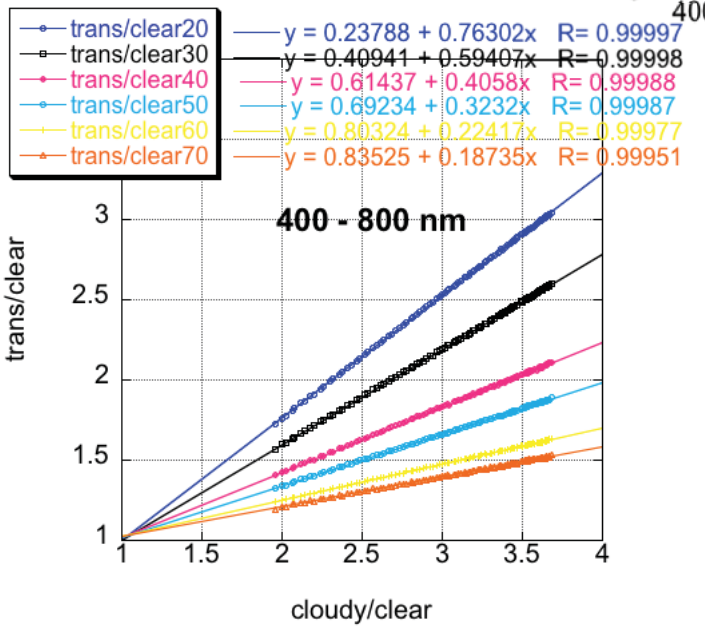
McBride P.J., A. Marshak, J.C. Chiu, K.S. Schmidt, Y. Knyazikhin, E.R. Lewis, W.J. Wiscombe, 2014. Studying the cloud particle size in the cloud-clear transition zone with surface-based hyperspectral observations. *J. Geoph. Res.* (submitted, April 2014).

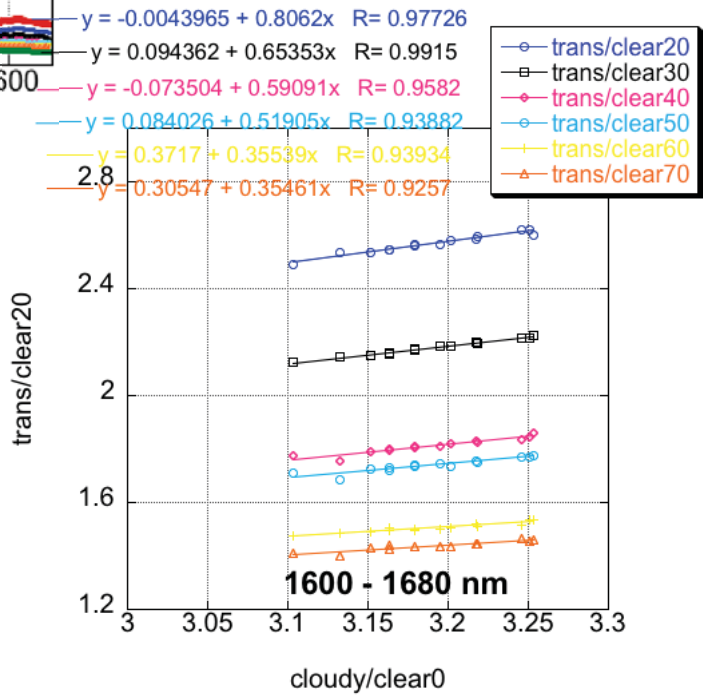
The paper uses MAGIC data as an example to show that changes in the effective radius (increase or decrease) can be successfully determined using the intercept in the NIR wavelengths

MAGIC July 15 SSFR data

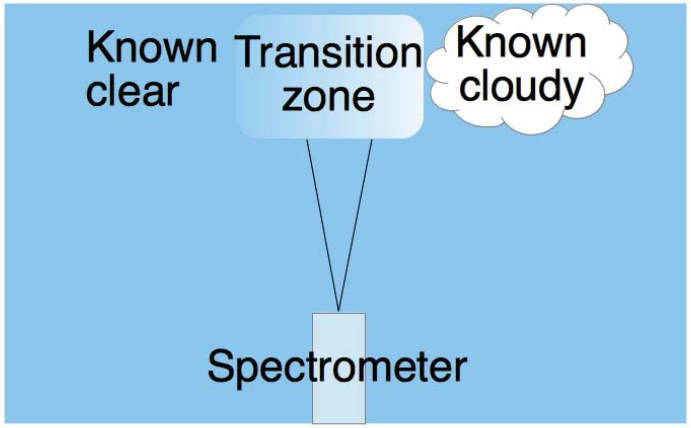








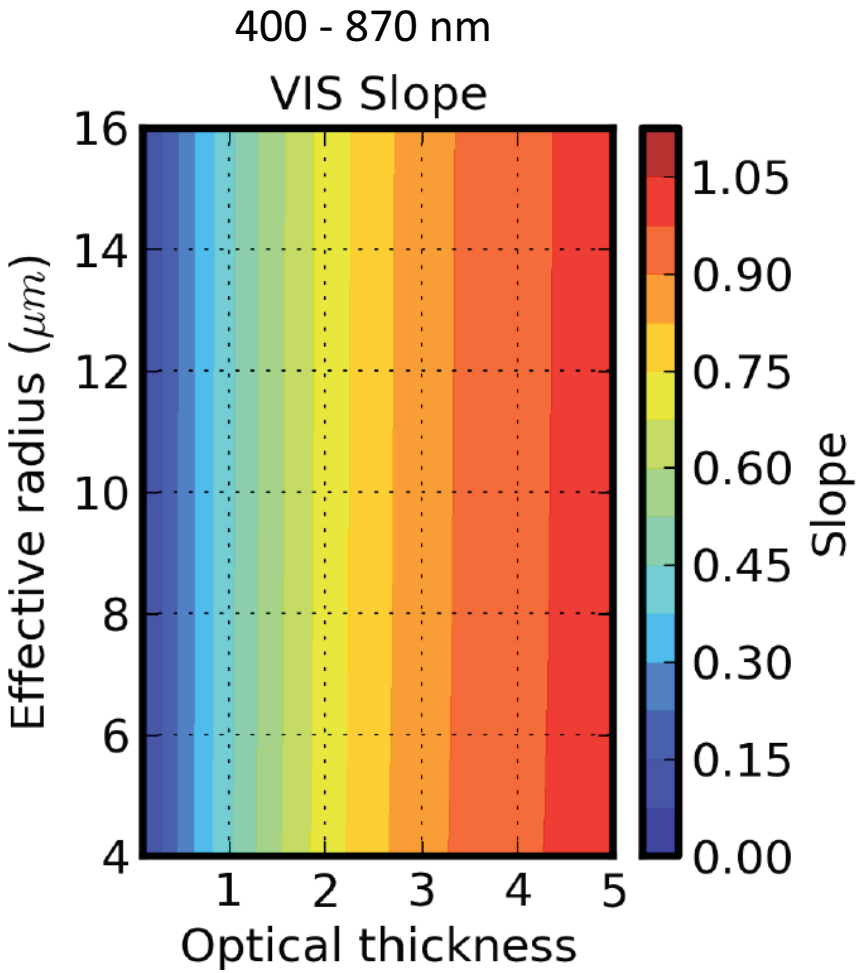
Cloud transition zone

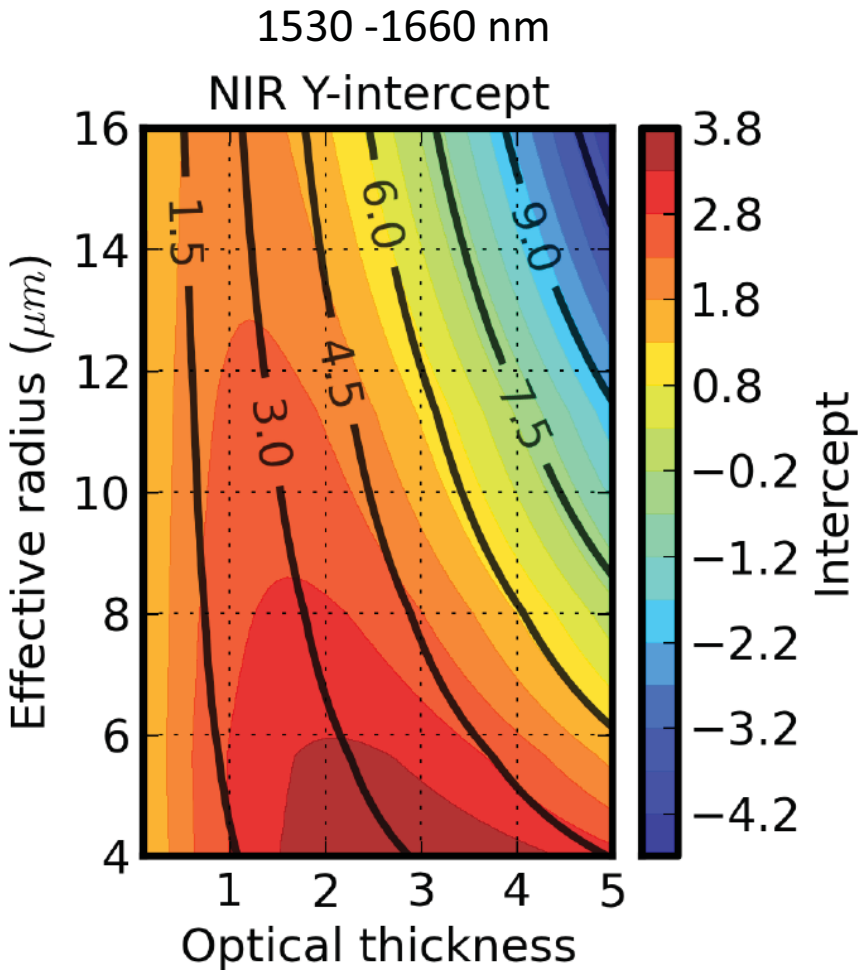


Retrieve ***qualitative*** cloud properties in the cloud transition zone using *a* and *b*.

$$\frac{I(t,\lambda)}{I(t_{known\_clear},\lambda)} = \frac{I(t_{known\_cloudy},\lambda)}{I(t_{known\_clear},\lambda)} a(t) + b(t)$$

Modeled slope and intercept

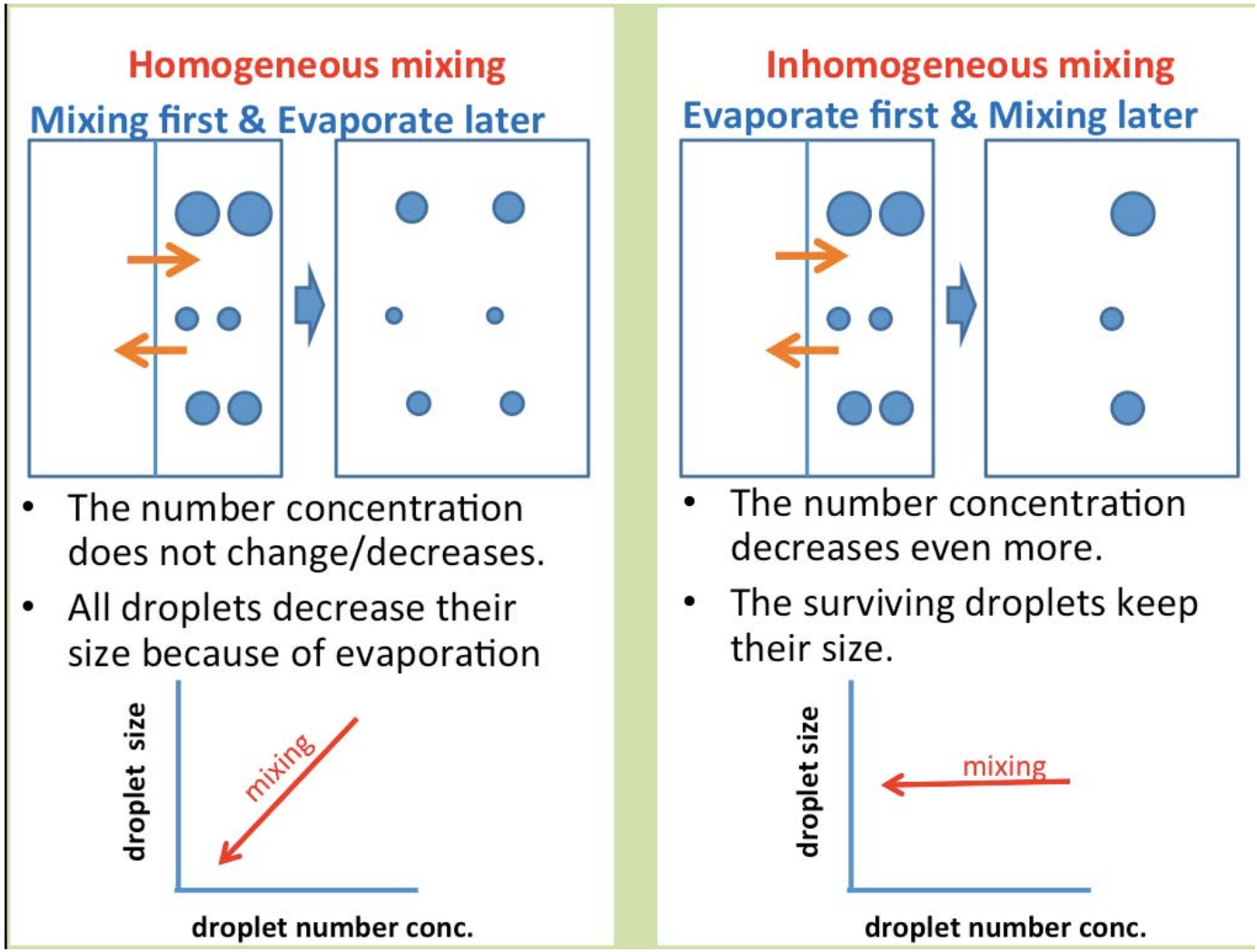




The black contours are % of cloud absorption at 1600 nm calculated with SBDART

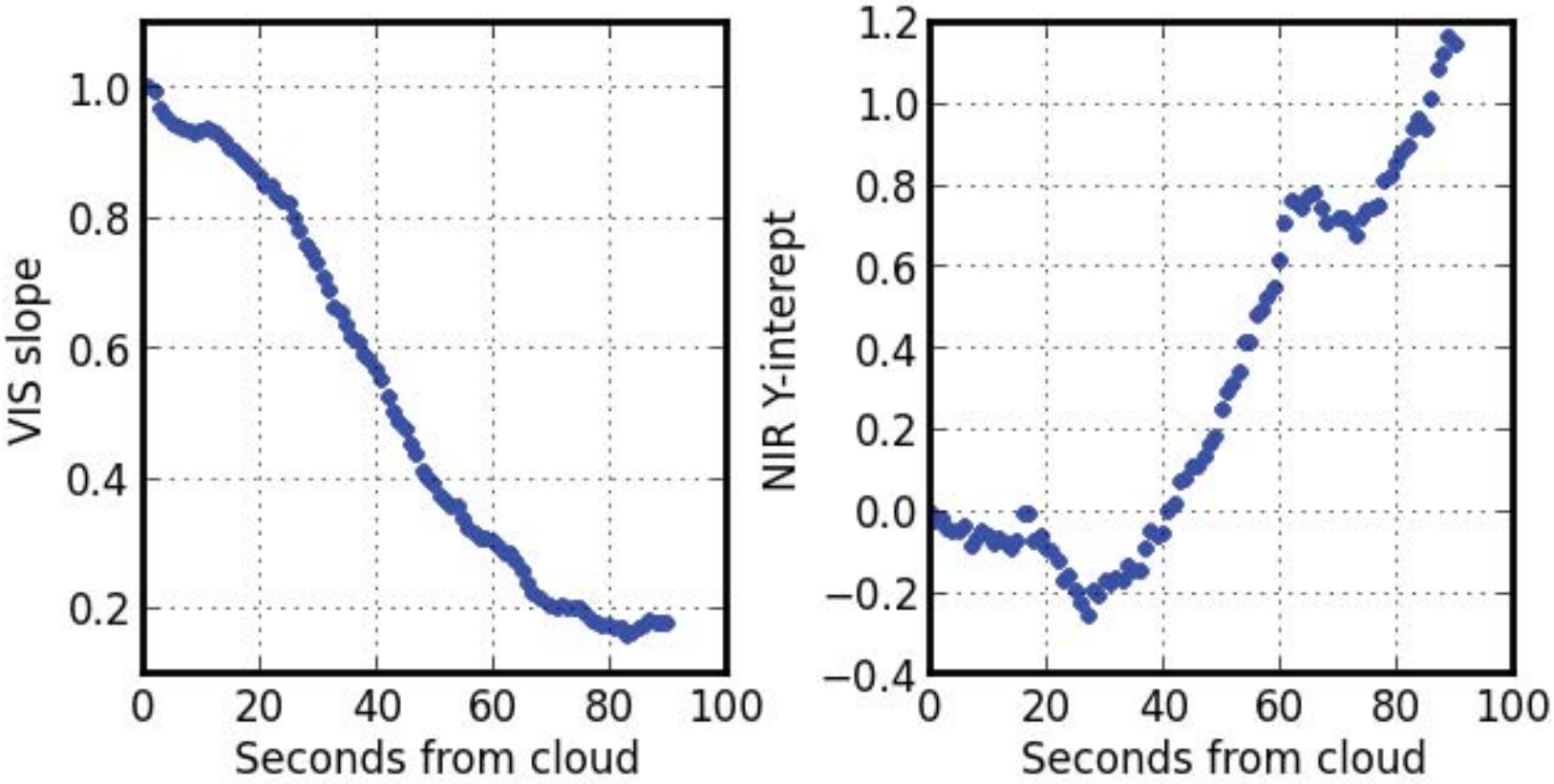
τ_{clear}=0.0

Cloud entrainment

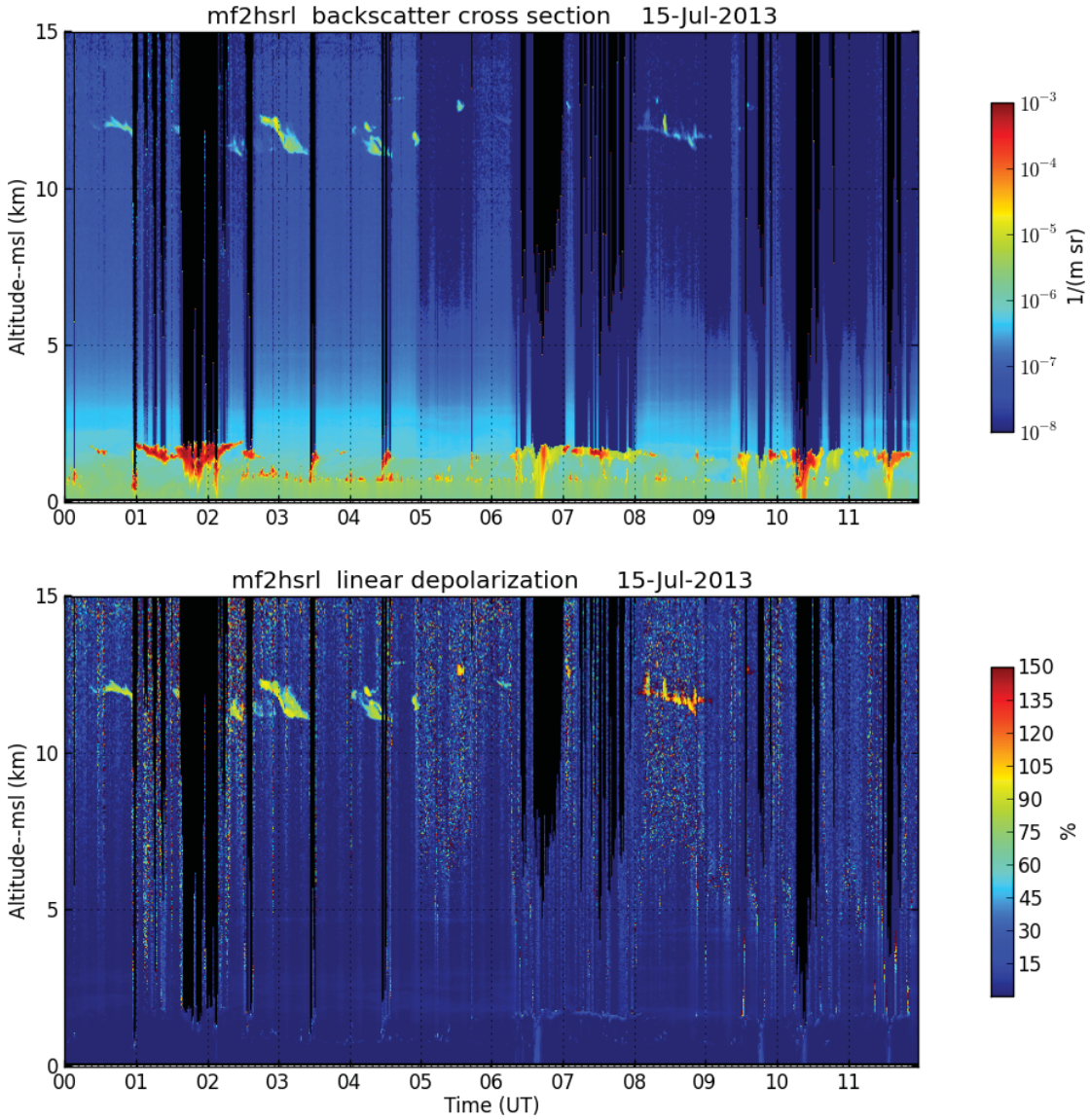


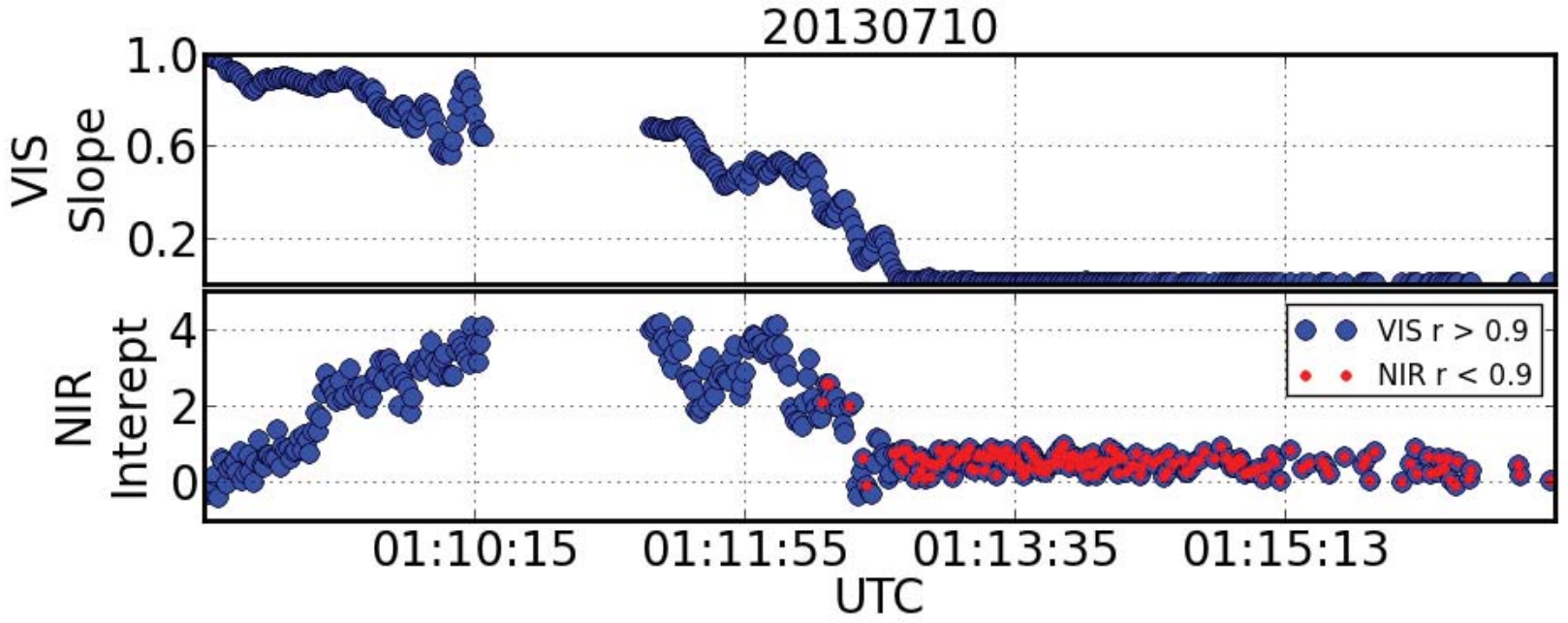
Slide courtesy of Greg McFarquhar

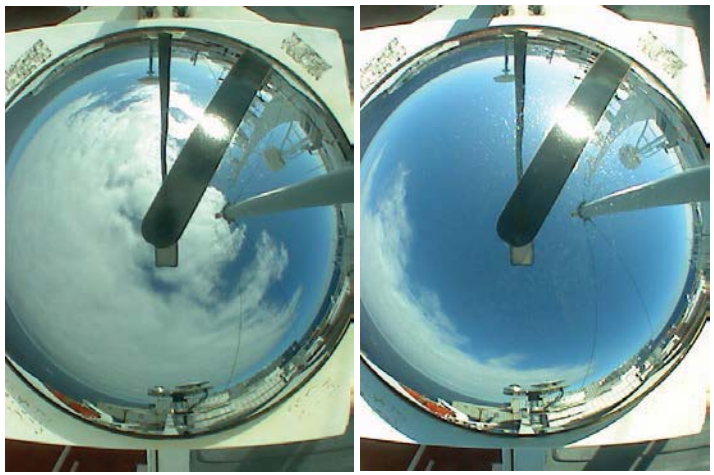
Transition zone from MAGIC



HSRL data

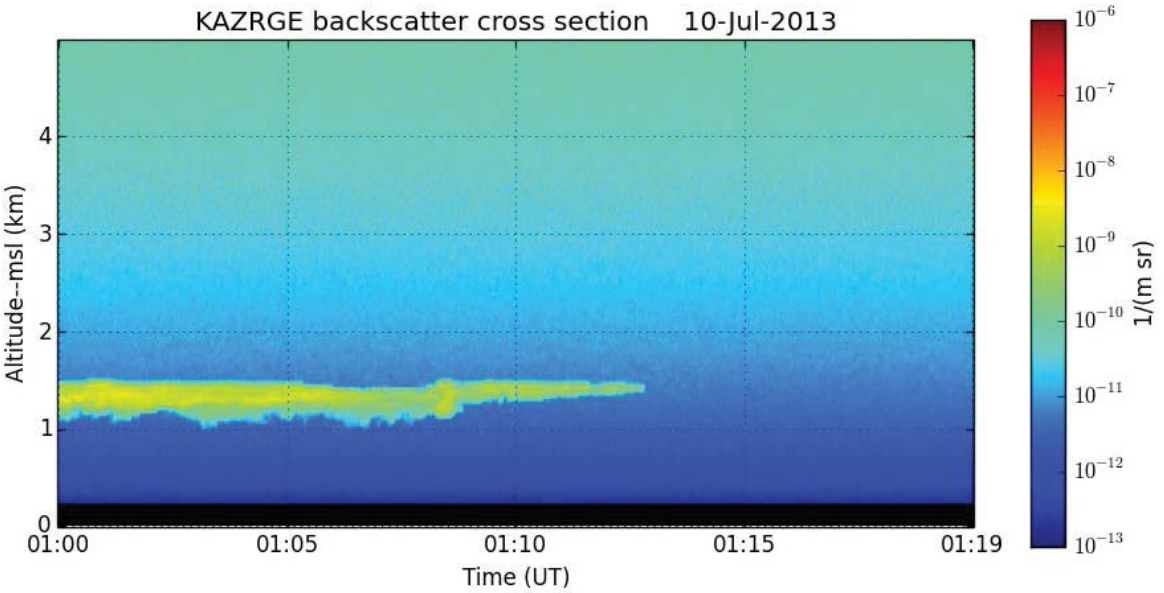

mf2hsrl backscatter cross section 15-Jul-2013
Altitude--msl (km)
15
10
5
0
00
01
02
03
04
05
06
07
08
09
10
11
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
1/(m sr)
mf2hsrl linear depolarization 15-Jul-2013
Altitude--msl (km)
Time (UT)
150
135
120
105
90
75
60
45
30
15
%

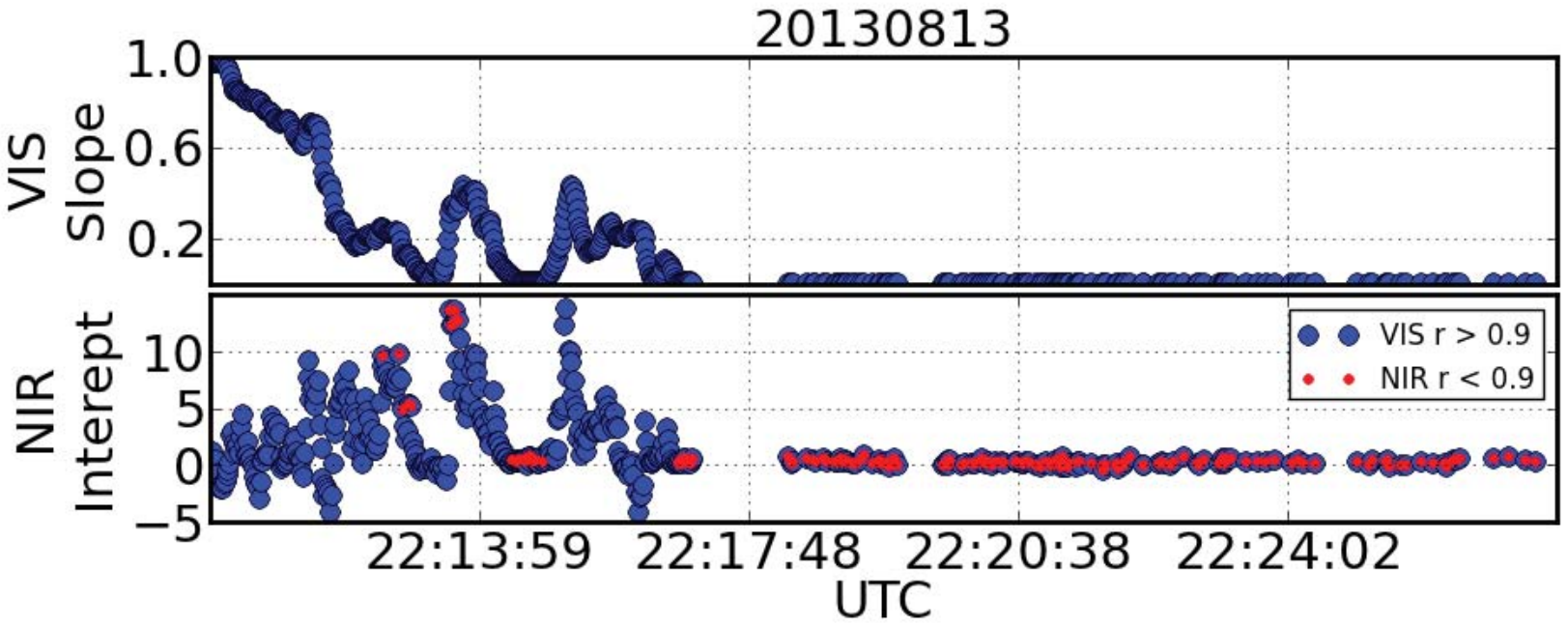


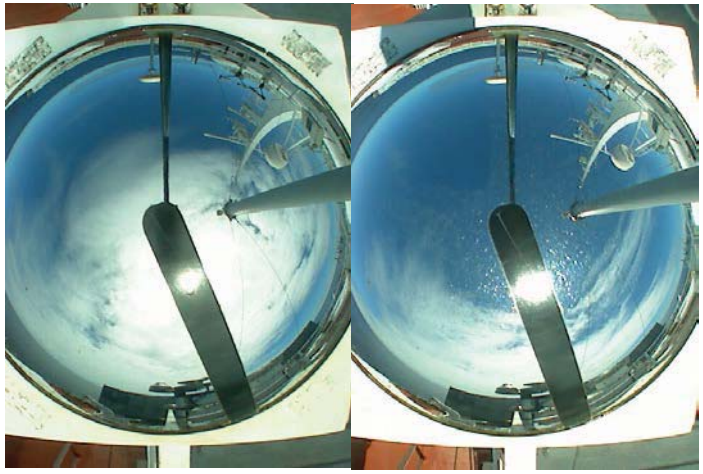


Known cloudy
01:08:30

Known clear
01:19:30

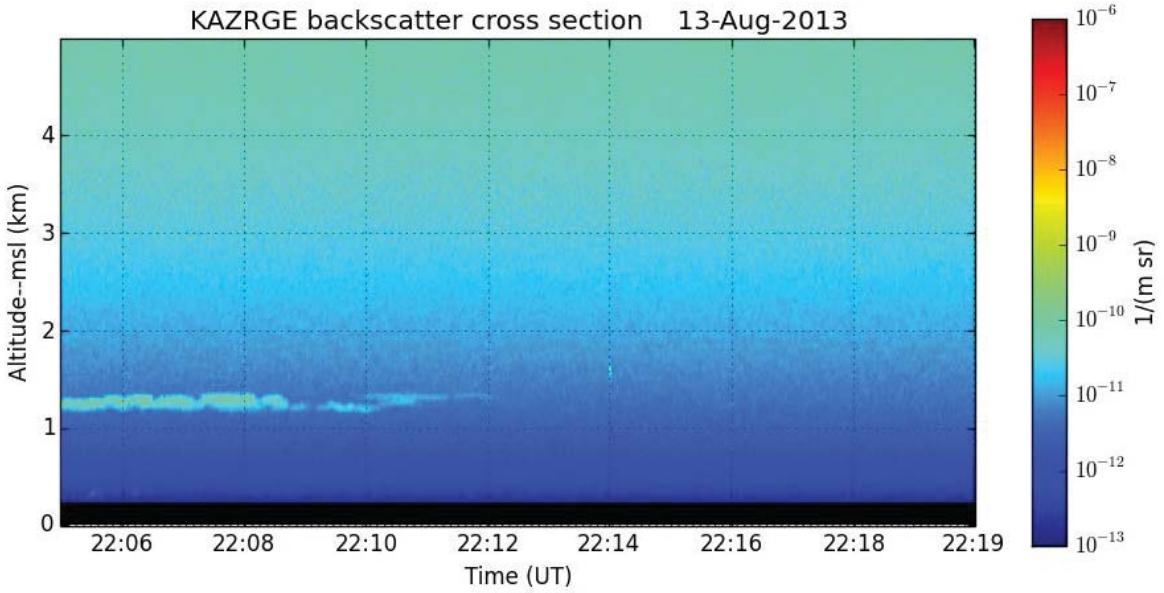


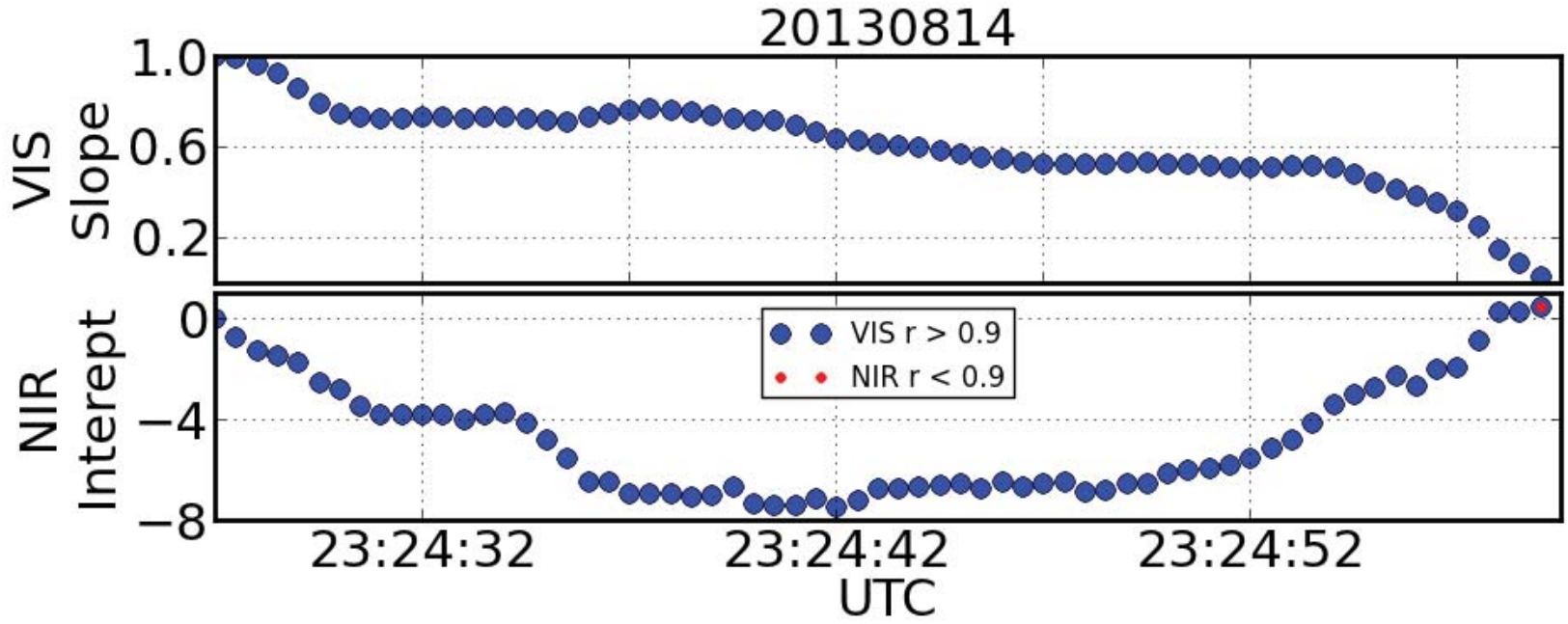


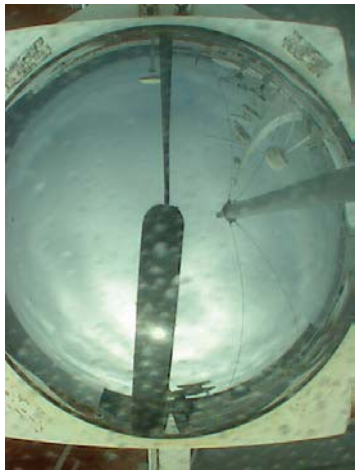


Known cloudy
22:07:00

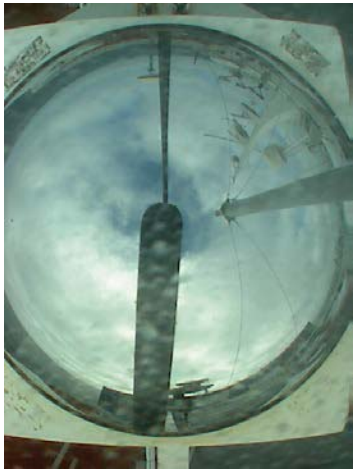
Known clear
22:18:00



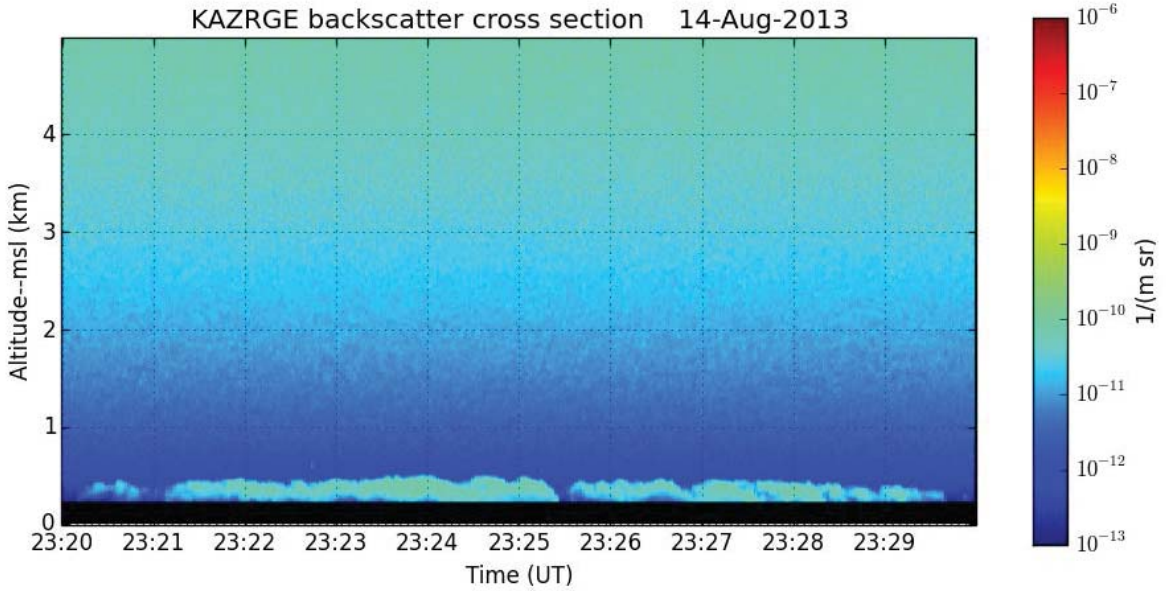




Known cloudy
23:24:30



Known clear
23:25:30



Summary

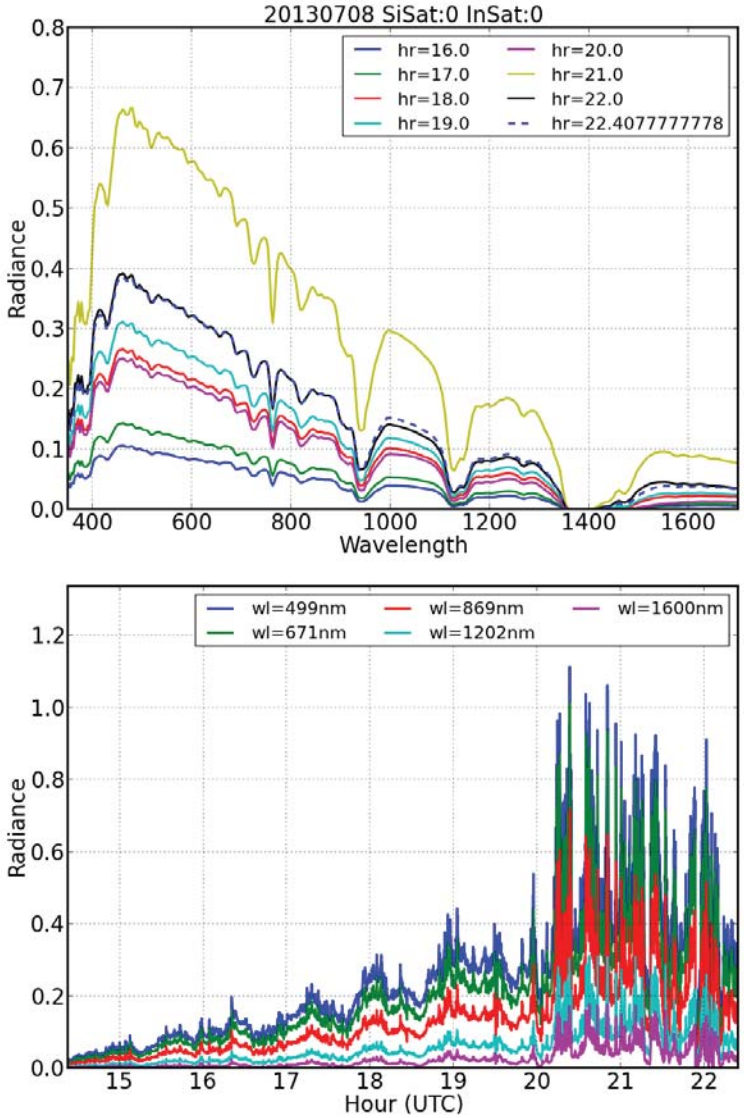
There are several shortwave (hyper)spectral instruments @ MAGIC (SAS-ze, FSSR, FRSR, Cimel).

The spectral observations are used (by our ASR team) to study aerosol and cloud properties in the transition zone in fully 3D cloud situations.

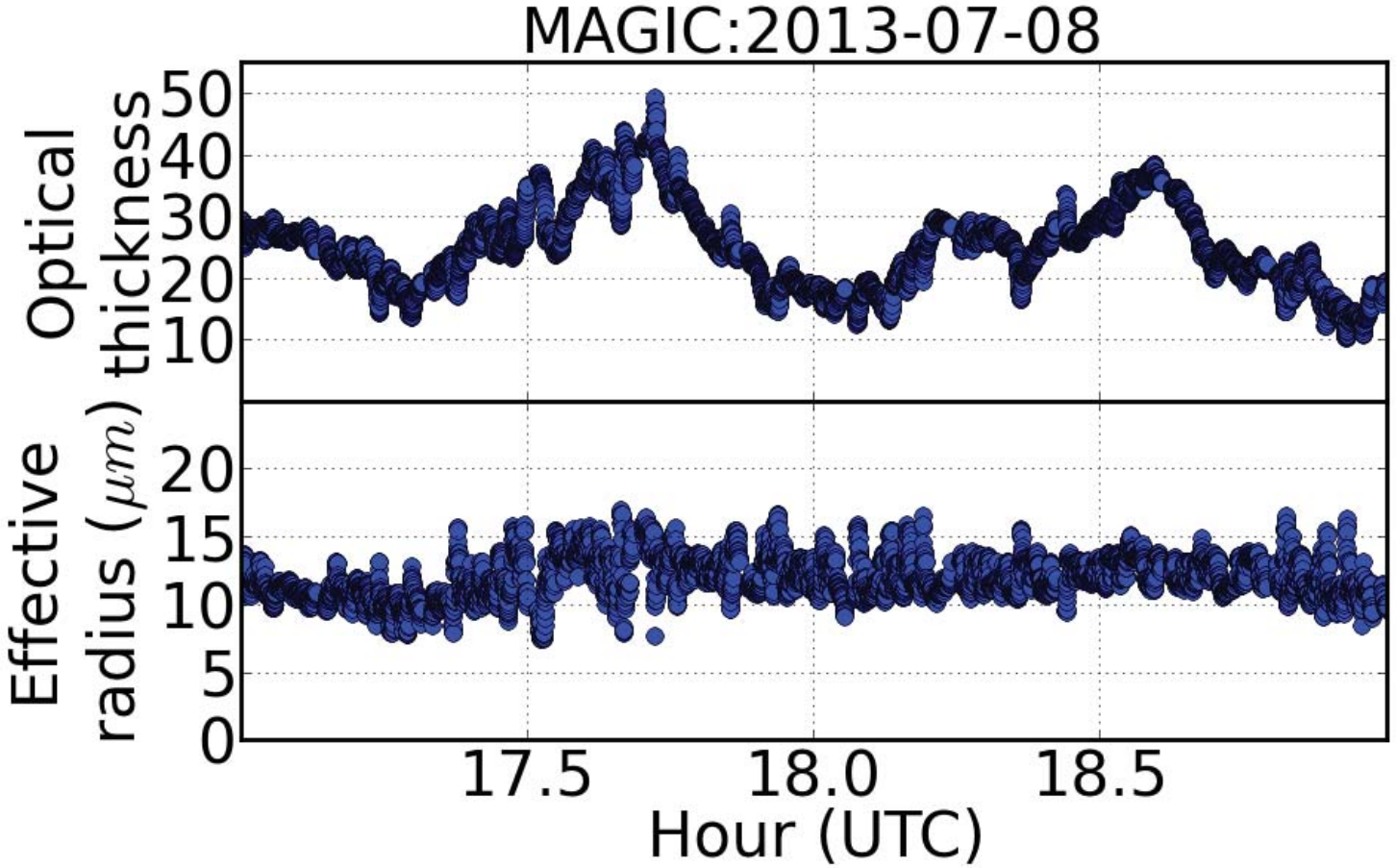
A new spectral technique has been developed and tested with RT simulations; it has been applied to MAGIC data on a case-by-case basis.

There are many (unresolved) issues that require more analysis; we are not yet ready to apply it to all MAGIC spectral data automatically to get the TZ statistics as a function of aerosol and cloud features.

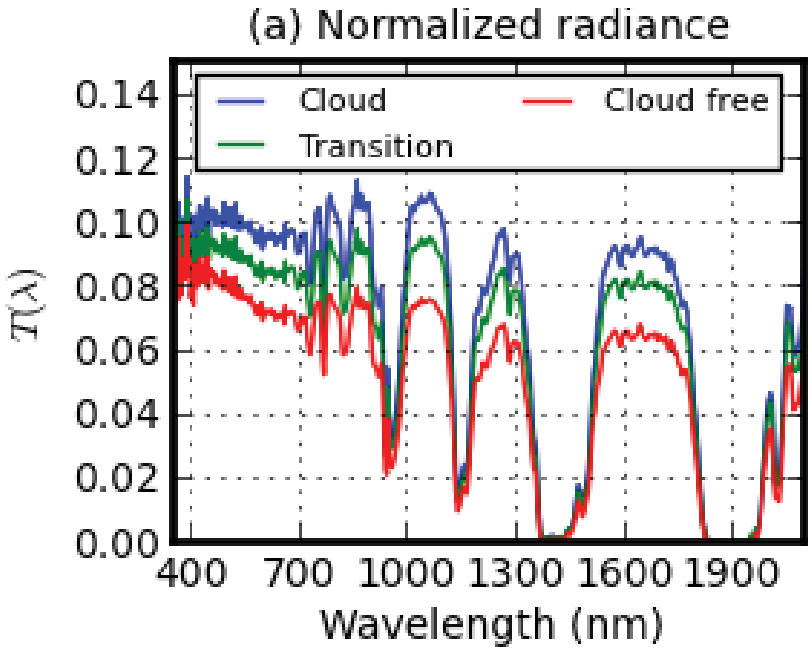
Cloud property retrievals



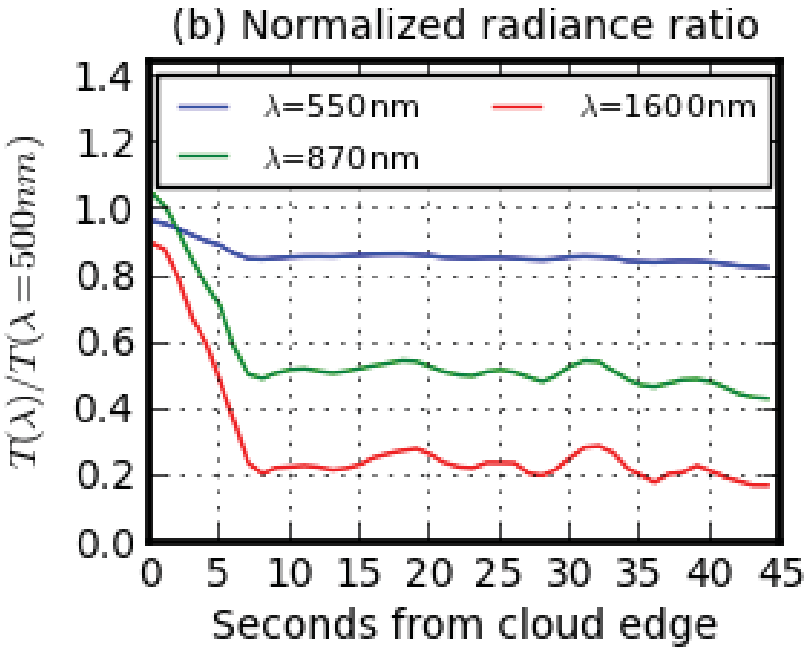
Cloud property retrievals



Zenith radiance spectra



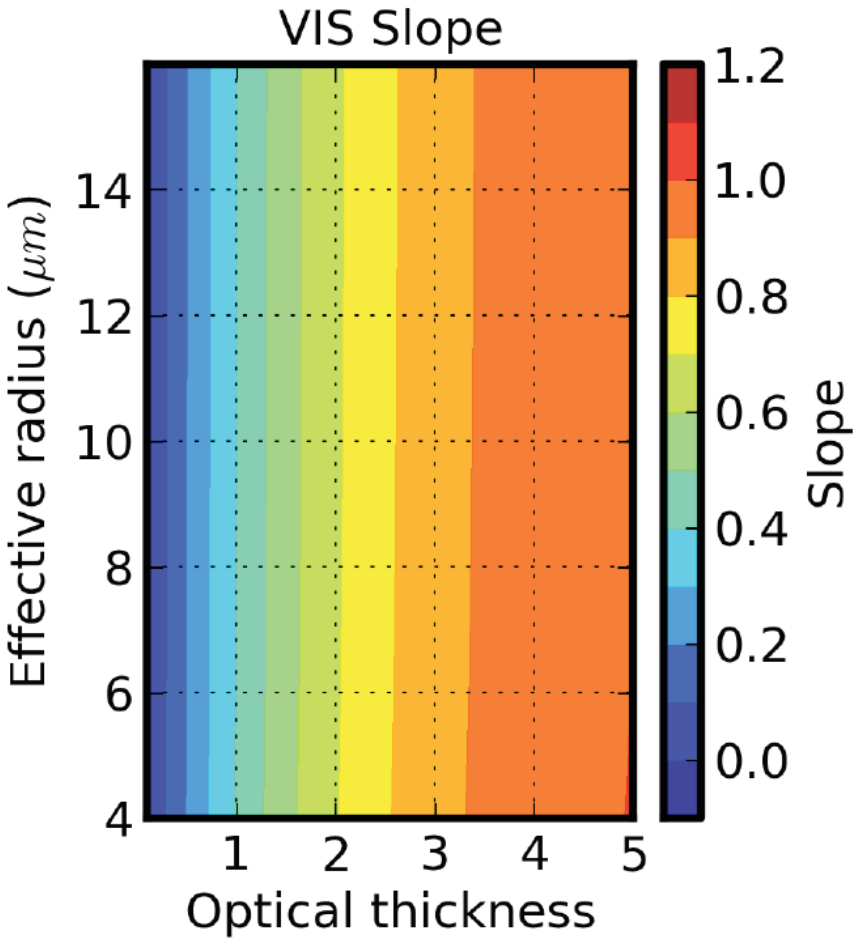
Taken at 22 and 44 s from cloud edge



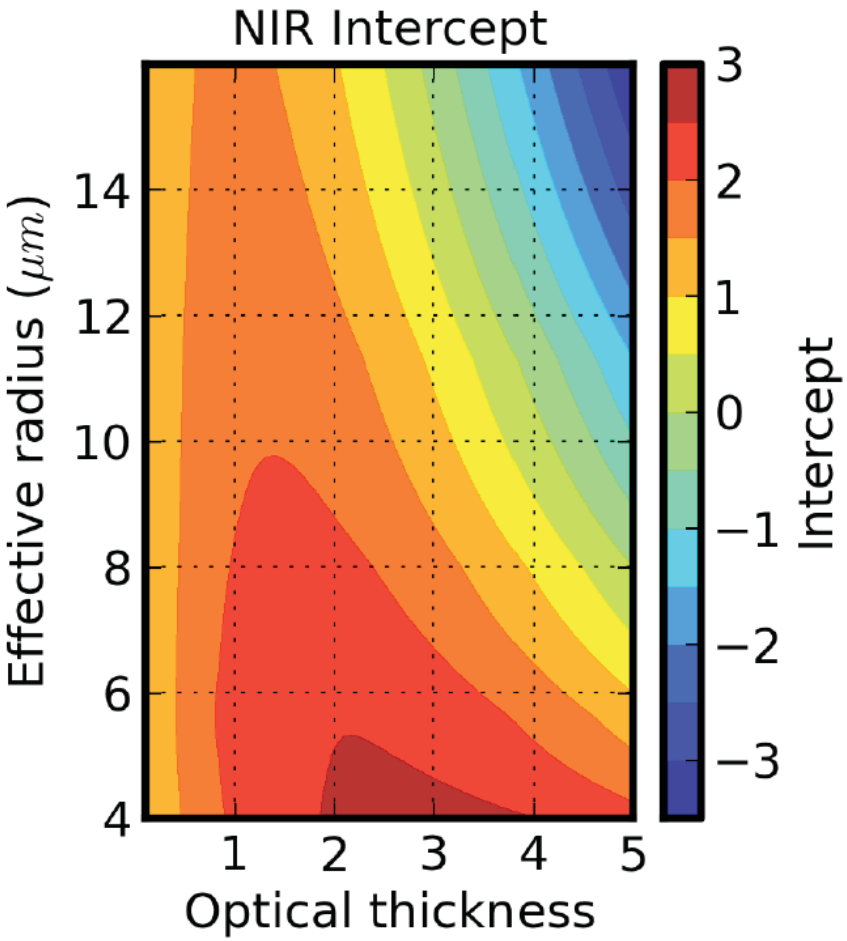
Time series of the ratio to 500 nm

Unknown "known clear"

400 - 870 nm



1530 -1660 nm



τ_{clear}=0.1